Eur. Phys. J. C (2018) 78:896
https://doi.org/10.1140/epjc/s10052-018-6367-y

THE EUROPEAN PHYSICAL JOURNAL C

Regular Article - Theoretical Physics

Cosmology in modified $f(R, T)$-gravity

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Received: 27 September 2018 / Accepted: 20 October 2018 / Published online: 3 November 2018

Abstract In the present paper we propose a further modification of $f(R, T)$-gravity (where T is trace of the energy-momentum tensor) by introducing higher derivatives matter fields. We discuss stability conditions in the proposed theory and find restrictions for the parameters to prevent appearance of main type of instabilities, such as ghost-like and tachyon-like instabilities. We derive cosmological equations for a few representations of the theory and discuss main differences with conventional $f(R, T)$-gravity without higher derivatives. It is demonstrated that in the theory presented inflationary scenarios appear quite naturally even in the dust-filled Universe without any additional matter sources. Finally, we construct an inflationary model in one of the simplest representation of the theory, calculate the main inflationary parameters and find that it may be in quite good agreement with observations.

1 Introduction

According to current knowledge, based on experimental data, there were (at least) two different epochs of dynamical evolution of our Universe when the key role was played dark energy (DE): an inflationary stage at the early times of evolution and a late time acceleration (l.t.a.) stage, which started recently (on cosmological scales) and continues till modern time. We know about the existence of modern DE (associated with l.t.a.) with high precision from the different experiments, the first of which relate to SNI data [1,2], whereas about primordial DE (associated with inflation) we know only by indirect detection such as general isotropy and flatness of observable part of Universe and the non-flatness spectrum of primordial scalar perturbations [3,4]. Nevertheless the true nature of both DEs is unknown yet and this fact stimulates researchers to find solutions of the DE problem outside of standard physics.

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Modifications of the gravitational sector are well known from early times and still are very popular, because different corrections to the gravitational action follow for instance from string theory [5,6] and one-loop quantum effects [7–9] (see also [10,11] for cosmological applications). The number of different approaches in this way is actually huge and we only mention here examples such as $f(R)$-gravity [12–14], Horndeski theory [15], unimodular gravity [16], teleparallel gravity [17], theories with non-minimal kinetic coupling [18]; see also [19].

Nevertheless there is another possibility to solve DE problem: we can introduce some exotic matter or modify the right hand side (matter sector) of the equations. The activity in this direction is not so intensive, but we can mention such attempts as phenomenological higher derivative matter fields [20,21], bulk viscosity and imperfect fluids [22–24], theories with non-minimally coupled Ricci scalar with matter lagrangian [25,26] and one of the most popular subclasses of this model, $f(R, T)$-gravity [27], where T is the trace of the energy-momentum tensor (stress-energy tensor). Note that the dependence on T may be induced by exotic imperfect fluids or quantum effects (such as the conformal anomaly). Also we can study such kinds of models as some phenomenological models, which arise from some more general theories. Indeed it is well known that brane models can modify exactly the r.h.s. of the equations of motions on the brane [28–31]. For these reasons in our paper we try to discuss a wider class of $f(R, T)$-gravity models and incorporate a function dependence by the derivatives of T (models containing $\Box R$-terms also are known as possible modifications of $f(R)$-gravity [32,33]).

This paper is organized as follows: in Sect. 2 we derive general equations and discuss stability conditions; in Sect. 3 we study a few concrete examples of functions and find some cosmological solutions; in Sect. 4 we estimate inflationary parameters for one of the simplest shapes of the function; and in Sect. 5 we give some concluding remarks.